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VI.—*On the relations of cloud and rainfall to temperature in India, and on the opposite variations of density in the higher and lower atmospheric strata.—By* Henry F. Blanford, F. R. S., *Meteorological Reporter to the Government of India.*

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In the Report on the Meteorology of the year 1879, which I drew up last autumn, and which will shortly be issued, I had occasion to discuss the two subjects enumerated in the above title, in connection with the anomalous variations of temperature and barometric pressure, exhibited by the Indian registers during the last two or three years. As, however, they have a much wider bearing than merely in reference to the cotemporary phases of our Meteorology, and indeed may claim to rank among the more important physical operations which influence Indian Meteorology, I have thought that it might be of interest to extract these notices from their original setting in the pages of the Annual Report, and to ask the Society to give them an independent circulation in its Journal.

I have been the more prompted to do this, because, in a recent number of the Journal of the London Meteorological Society,* Mr. Douglas Archibald has discussed at length a nearly cognate subject, *viz.*, the "Variations in the barometric weight of the Lower Atmospheric Strata in India." In this paper, Mr. Archibald refers to certain articles which the late Mr.

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J. Allan Broun, F. R. S. contributed to "Nature" shortly before his decease, and in which he endeavoured to show, that while air must unquestionably expand and contract according as its temperature rises and falls, the variation in density so produced in no way adequately accounts for the annual variation of monthly mean barometric pressure at the surface of the earth. Mr. Archibald, following a method which I proposed in a paper in the Phil. Trans. in 1874, computes the variations of density, which the atmospheric column below Darjiling undergoes month by month, in consequence of the variations of temperature, humidity and top-pressure; and shows that the lower stratum of the atmosphere, thus subjected to a physical analysis, conforms in its changes, with near approximation, to the indications of theory; and that, of the several causes affecting its density and static pressure, temperature is by far the most influential. This conclusion is also that at which I arrived in the paper above referred to, working on far more restricted data than those discussed by Mr. Archibald, but the best then available to me.

Mr. Archibald has taken as the subject matter of his paper, the normal or average values of pressure, temperature &c., as given by many years' registers at Darjiling and Goalpara. In the latter part of the present paper, I have compared the abnormal variations of temperature with those of the density of the atmospheric column, below the three hill stations Chakrata, Ranikhet and Pachmarhi, and have shown that, in their case also, temperature and density vary inversely, in accordance therefore with the results previously obtained by myself and Mr. Archibald, and in accordance also with the indications of theory.

It seems, therefore, to be fairly established that, as regards the lower stratum of the atmosphere, the anomaly pointed out by the late Mr. Broun does not exist. Observation and theory are here as consistent as the character of the data would lead us to anticipate; and we must therefore look to the condition of the higher strata of the atmosphere, those which lie above the level of our Indian hill stations, Darjiling, Chakrata &c., for the explanation of the apparent inconsistency to which Mr. Broun drew attention. In connection with this enquiry, the facts brought forward in the present extracts from my report seem to me to have much significance.

I may mention that the whole of this was written and in type (for the Report) before I had seen Mr. Archibald's paper above referred to.

Some other general questions of importance are referred to incidentally in the course of discussion, in the extracted passages.

On the mean of all Indian stations, the temperature of the year 1879 was slightly below the average, but it was by no means generally so in Northern India. In the North-West Provinces and Bengal, the mean temperature of the year was slightly excessive ; and in the Punjab, this was the case at as many stations as showed the opposite variation. This excess was due to the preponderance of the high temperatures of the first five months, which were not quite compensated by the depression of temperature which prevailed during the rains, and, more or less generally, in the later months of the year. In the Central Provinces, however, and Rajputana, the great depression of the closing months of the year more than counterbalanced the excess of the earlier months ; and in the Dakhan and the Peninsula generally, a depression of temperature characterised the greater part of the year. In Burma and Arakan, only the first three months of the year showed an excess of temperature ; that of the remainder of the year being rather below the average.

Thus the progressive increase of the average temperature of India, which, as was shown in the Meteorological report for 1878, had been in progress during the four years 1875-78, reached its climax in the last of these years, and has been followed by a considerable fall. The mean anomalies of the five years are as follows :—

	1875.	1876.	1877.	1878.	1879.
Number of Stations	72	72	74	74	70
Mean anomaly	—0·29°	+0·08°	+0·17°	+0·62°	—0·13°
Progressive variation	..	+0 21	+0·25	+0·45	—0·75

The result, therefore confirms the conclusion which I drew in the Meteorological report of 1878, and shows that the variation is not apparent only and due to any progressive change in the instruments employed. So far, it coincides with that found by Gautier and Köppen for land stations in the tropics generally ; since the maximum coincides, approximately, with the recent minimum of sun-spots.

A recent notice by Dr. Köppen, in the July number of the Journal of the Austrian Meteorological Society, gives some highly interesting data of the temperature anomalies of large land areas of the Northern Hemisphere, during the last five years ; which indicate that the oscillation of temperature, shown above, was not restricted to India, but was shared by a large portion of Europe and North and Central America. The data are reproduced in the following table, in which the temperature anomalies are reduced from Dr. Köppen's table, to their corresponding values in Fahrenheit degrees :—

	1875.	1876.	1877.	1878.	1879.
Central Europe, ...	—1·06	—0·14	+0·23	+0·59	—2·32
Eastern North America, ...	—2·30	—0·31	+2·02	+3·38	+0·38
San José Central America 10° N., ..	—0·72	—0·07	+1·31	+1·55	—0·47
European Russia South of 55° N., ..	—2·34	—0·72	—0·36	+1·80	?
Ditto ditto North, ,, ..	—3·42	—1·08	—0·36	+2·70	?

In another table Dr. Köppen gives the temperature anomalies of the same years for those parts of Europe and Asia which show a departure from this regular oscillation. It is to be observed that these include all those countries which are most directly influenced by the Gulf-stream :—

	1875.	1876.	1877.	1878.	1879.
Scandinavian Peninsula, ..	—0·92	—1·06	+1·96	+0·90	—1·04
England, ...	—0 14	+0·52	+0·11	+0·18	—3·20
Scotland, ...	+0·49	—0·16	+0·74	+0·36	—2·05
Iceland and Faroe Isles, ...	+2·2	+0·9	—0·7	—0·5	+0·4
West Greenland, ...	+1·8	+0·9	+1·8	+3·6	?
Italy, ...	—0·7	+0·2	+0·4	..	?
Caucasus, 4 Stations	—0·7	+1·3	+1·1	+0·4	?
South-West Siberia and Amu Darya, 6 Stations, ...	..	—0 7	—0·5	+1·1	?
South-East Siberia and Pekin, 4 Stations, ...	+0·2	+0·4	+0·2	—0·02	?

The subject of Dr. Köppen's paper appears to have been suggested by a paper of Mr. Douglas Archibald's in 'Nature' (26th February 1880), wherein it is sought to show that the periodical heat waves, brought to light by Professor Piazzi Smyth, on the evidence of the rock temperatures of Calton Hill, Edinburgh, are dependent on variations in the mean cloudiness of the atmosphere ; since the periods of highest ground temperature are those of minimum cloud and *vice versâ*. This view of Mr. Archibald's, *viz*., the dependence of temperature on cloud proportion, appears to be in part identical with that which I put forward originally in my paper, "On some recent evidence of the variation of the Sun's Heat," &c., in the XLVth Volume of this Journal (June 1875), wherein I endeavoured to show that, the temperature of the lower atmosphere, on the land surface, in India, depends much more on the quantity of cloud and on the rainfall than on that variation of the solar heat intensity, the periodicity of which was brought out in the data discussed in the paper. As regards India, I go beyond Mr. Archibald, however, in attributing even greater importance to the evaporation of rainfall than to obscuration of the sun by cloud.

In a short paper, written in reply to some criticisms of Dr. Hann and Dr. Köppen, which I have lately communicated to the Journal of the Austrian Meteorological Society, I had given some recent data which bear strongly on these views ; since they show that both the ground temperature and that of the lowest stratum of the atmosphere are dependent, in a very high degree, on cloud and rainfall; and that, in India at least, this effect is so great, that it must, in all probability, outweigh and mask any direct influence of variations in the intensity of the solar radiation.

In the first place, I give a comparison of the mean temperatures of the air and ground at Alipore (Calcutta) Observatory, in the first five months of the two years 1879 and 1880. The air temperatures are those recorded under a shed of the usual pattern, consisting of a thatched roof simply supported on posts, and open, therefore, on all sides to the wind, beneath which the instruments are exposed, about 4 feet above the ground. The ground temperatures are obtained with a verified standard thermometer, the bulb of which rests on the ground at the bottom of a wooden tube, 3 feet below the surface, the arrangement being similar to that known as Lamont's. The place of exposure is a grassy surface, (the grass being short and in the dry weather thin), freely exposed to sunshine and rain :—

	Temperature.				Cloud proportion.		Rainfall : inches.		Rainy days.	
	Air.		Ground.							
	1879.	1880.	1879.	1880.	1879.	1880.	1879.	1880.	1879.	1880.
January, ..	65·0	65 8	72·4	72·6	0·39	2·03	*Nil*	0·05	...	1
February, ...	71·7	69·9	74·5	74·7	1·74	3·05	0·21	2·91	1	6
March, ...	79·1	78 6	79 8	78·3	0·79	2·72	*Nil*	0·54	...	2
April,.........	85·2	84 2	86·3	84 1	2·43	2·64	*Nil*	1·91	...	6
May, ...	85·2	83·6	90·2	85·5	4·59	5·21	3·22	4·87	9	12
Mean or Sum	77 2	76·4	80·6	79·0	1·99	3·13	3·43	10·28	10	27
Difference,...	...	—0·8	...	—1·6	...	+ 1·14	...	+ 6·85	...	+17

Hence, it appears that, in the month of January, an excess of 1·64 of cloud, with an insignificant rainfall, accompanied an increase of 0·8° of air temperature. But in February, an increase of only 1·31 of cloud and of 2·70 inches of rain lowered the mean temperature 1·3°. In March, an increase of 1·93 of cloud and of 0·54 inch of rain, on only two days, coincided with a reduction of 0·5°. In April, an increase of only 0·21 of cloud and 1·91 inches of rain, on six days, a reduction of 1·0°; and, in May, an increase of 0·62 of cloud and 1·65 inches of rain, on three additional days, a reduction of 1·6° of temperature. But the temperature of the ground, in which the cooling effects of cloud and rain, (the latter especially,) are cumulative, exhibits their influence in a far more striking manner. As the result of the differences of the five months, the ground temperature of May 1880 was not less than 4·7° below that of the corresponding month of 1879.

That the effect of the cloud and rainfall on the temperature of the air was so much smaller than on that of the ground, is doubtless owing to the fact that, after January, the winds of Calcutta are chiefly from the sea. This too perhaps explains the very striking fact, that on the average of two complete years' observations, the temperature of the ground, at a depth of 3 feet, is not less than 5° higher than that of the air:

Such being the effect of cloud and rain, at a station situated only 60 miles from the sea, and but 20 miles from the broad estuary of the Hooghly, up which much of the sea wind blows to Calcutta, it may be expected that, in the continental climate of Upper India, this influence will be far more pronounced. That such is, in fact, the case, is strikingly shown by a comparison of the temperature, cloud and rainfall of the North-West Provinces in the dry and rainy seasons of 1877 and 1879 respectively. In the former year, the months of March, April and May were unusually cloudy, and the rainfall, although not excessive, was, on the whole, above the average. In 1879, these months were unusually dry and serene. On the other hand, the conditions of the rainy months, June, July, and August of the two years, were relatively reversed ; the rainfall of 1877 being very deficient, while that of 1879 was more copious than usual. The result of these variations on the temperature is well shown in the following table, which gives the mean temperature anomaly, the mean cloud proportion, monthly rainfall and number of rainy days deduced from the abstract registers of the five stations, Meerut, Agra, Lucknow, Allahabad, and Benares :—

	Temperature anomaly.		Cloud proportion.		Rainfall : inches.		Rainy days.	
	1877.	1879.	1877.	1879.	1877.	1879.	1877.	1879.
March, ...	—1·4	+0·9	3·85	2·47	0·58	0·18	2·0	1·4
April, ...	—4·0	+3·7	3·22	1 03	0 52	0·07	1·6	0·4
May, ...	—1·3	+4·7	2·63	1·38	0 43	0·02	1·6	0·6
Mean, ...	—2·2	+3·1	3·23	1·63	0·51	0·09	1·7	0·8
Difference, ...	...	+5·3	...	—1·60	...	—0·42	...	—0‘9
June, ...	+1·8	—0·8	3·26	4·66	1·40	4·78	3·0	9·2
July, ...	+4·3	—2·0	5·48	7·91	3·00	11·61	6·0	16·2
August, ...	+6·8	—2·0	4·41	8·07	3·21	11·14	4·8	22·6
Mean, ...	+4·3	—1·6	4·38	6·88	2·54	9·18	4·6	16·0
Difference, ...	...	—5·9	...	+2·50	...	+6·64	...	+11·4

It must not be overlooked that, both in the dry season and in such an autumnal season as that of 1877, cloudless weather is accompanied by hot westerly winds, while cloudy weather is usually characterised by comparatively cool easterly winds; and it may therefore be objected, that a large part of the temperature difference shown in the above table, is dependent on the wind and not on the local effect of cloud and rain. And this objection may be admitted, in so far, that the temperature effect is not strictly of local origin. But the heat of the westerly wind, itself, is simply owing to the dryness of the adjacent tract. For the heaviest rain that falls in the North-West Provinces in July and August is brought by westerly winds, which come from the Arabian Sea. These blow across Rajputana and Central India, the surface of which has then been cooled by the rain already fallen; and under these circumstances westerly winds are cool winds. The supposed objection, therefore, has no real validity.

The above data show that, both in the dry season and the rainy season, the anomalous temperature of the air depends principally on the cloud and rainfall; the effect of both these being to lower the temperature; in the case of the former, by obscuring the sun, in that of the latter, by the evaporation which ensues, and which reduces the temperature of both the ground and the air in contact with it, not only on the days of rainfall, but generally for one or two days afterwards. In November and December, however, when the temperature is falling rapidly, the influence of these agents is relatively less powerful, and the final result is of a different character. In these months, the total loss of heat by radiation from the ground, under a clear sky, exceeds the total gain from solar radiation under similar conditions; and, accordingly, the presence of cloud, which tends to arrest both, results in maintaining the temperature above the average. The winds, which bring the vapour to form the cloud, also contribute to maintain a high temperature; since they come from the seas around India, the temperature of which, at this season, is higher than that of the land. It is true that, in the cold season, as in the hot dry season, a warm period due to southerly winds and cloud, if rain falls, is almost always followed by a few days of excessive cold, as in the dry season; but, on the whole, the former effect is preponderant; and in November and December accordingly, the rule which holds good for the greater part of the year is reversed, cloudy and rainy months having a positive, and clear dry months a negative, temperature variation. This is well shown by the following table, which gives the mean temperature anomaly, cloud proportion, rainfall and number of rainy days of the six Punjab stations, Dera Ismail Khan, Rawalpindi, Sialkot, Lahore, Ludhiana, and Delhi, for November and December, in each of the five years 1875-79 :—

Months.	1875.				1876.				1877,				1878.				1879.			
	Temperature anomaly.	Cloud proportion.	Rain : inches.	Rainy days.	Temperature anomaly.	Cloud proportion.	Rain : inches.	Rainy days.	Temperature anomaly,	Cloud proportion.	Rain : inches.	Rainy days.	Temperature anomaly.	Cloud proportion.	Rain : inches.	Rainy days	Temperature anomaly.	Cloud proportion.	Rain : inches.	Rainy days.
November,	+1·0	2·29	0·15	0·8	+0·2	2·19	0·45	0·8	+4·0	3·64	2·08	2·7	—0·6	0·22	...	...	—2·5	0·61	...	...
December,	+2·1	2·51	1·03	2·2	+1·0	2·23	0·05	0·2	+0·7	5·27	3·90	4·7	—0·5	0·94	0·10	0·5	—1·0	1·80	0·70	1·8

Hence, it appears that, the months of November and December have a temperature above the average in cloudy years, below it in clear and serene seasons. It is hardly to be expected that the anomalies of temperature and cloud should show a more definite numerical relation than is exhibited in the table, since the actions concerned are somewhat complicated; and while the influences of cloud and of the wind on which the cloudiness depends, are such as tend to raise the temperature, the evaporation of rain, as already pointed out, tends to lower it. That the preponderating agency is that of nocturnal radiation, receives confirmation from the figures in the following table, which is based on the register of the same six stations in the Punjab. This shows, together with the temperature anomaly of the months in question, the anomaly of the nocturnal depression of the thermometer for terrestrial radiation, and also that of the solar thermometric excess. The signs *plus* and *minus* indicate the magnitude of the effect in each case, *i. e.*, the variations of these temperature differences, as compared with the corresponding respective averages. A + sign indicates a greater nocturnal depression (below the air temperature) than the average, or a greater excess of the solar thermometer (above the air temperature) and *vice versâ*. The comparison is restricted to the last three years, for which alone we have comparable observations of the nocturnal radiation.

Months.	1877.			1878.			1879.		
	Air temperature anomaly.	Nocturnal depression anomaly.	Solar excess anomaly.	Air temperature anomaly.	Nocturnal depression anomaly.	Solar excess anomaly.	Air temperature anomaly.	Nocturnal depression anomaly.	Solar excess anomaly.
November, ...	+4·0	—1·6	—2·5	—0·6	+1·0	—0·7	—2 5	+0 7	+1·7
December, ...	+0·7	—1·7	—3·6	—0·5	+1·0	+1·4	—1·0	+0·8	+0·2

In every case, the air temperature anomaly has the opposite sign to that of the nocturnal depression, indicating that, when the loss of heat by nocturnal radiation is less than usual, the mean air temperature of the month (not of the night only) is above the average; and that when the nocturnal radiation is greater than usual, the mean air temperature is below the average; and this action is sufficient to outweigh the varying intensity of solar radiation.

It is only in the months of November and December, that the air temperature shows, distinctly, the predominant influence of nocturnal radiation, as affected by cloud. In October, solar radiation on the one hand, and evaporation on the other, seem to be more effectual in influencing the air temperature than the variations of nocturnal radiation; and thus, an excess of cloud is more frequently accompanied with a negative than a positive anomaly of air temperature. In January, the two kinds of action are more nearly balanced. This conclusion is illustrated in the following table, which exhibits the mean results of the six Punjab stations above enumerated in the five years 1875-79.

Months.	1875.				1876.				1877.				1878.				1879.			
	Temperature anomaly.	Cloud proportion.	Rain in inches.	Rainy days.	Temperature anomaly.	Cloud proportion.	Rain in inches.	Rainy days.	Temperature anomaly.	Cloud proportion.	Rain in inches.	Rainy days.	Temperature anomaly.	Cloud proportion.	Rain in inches.	Rainy days.	Temperature anomaly.	Cloud proportion.	Rain in inches.	Rainy days.
January, ..	—0·2	2·71	0·09	0·7	+0·7	3·21	0·68	1·3	+0·9	5·55	2·54	4·3	—0·8	3·34	0·62	1·3	+2·2	2·12	0·10	0·2
October, ..	—2.8	0·63	0·83	1·5	—1·8	2·08	1·13	2·8	—0·3	2·71	1·88	2·7	+2·6	0·47	0·13	0·2	+0·6	0·42	0·13	0·2

In any discussion of the causes which affect the temperature and modify the temperature anomaly of any given month or other short period, there is one important circumstance which must not be overlooked, although it is rarely referred to in the discussion of such questions. This is the temperature of the ground. It seems to be established by the observations of ground temperature, which have been made at Calcutta during the last two years, that the ground, to a considerable depth, serves as a reservoir of heat, the slow emission of which probably exercises an appreciable influence on the temperature of the lowest air stratum; and this will be more especially the case in a region such as the Punjab, where (in the cold season more particularly) the air has but little movement of translation. This effect becomes apparent, when two or three months, in succession, are characterised by abnormal dryness or its opposite, by the gradual exaggeration of the temperature anomaly, whether positive or negative, in the successive months. Of this phenomenon, examples have been given in the table on a previous page, more especially in the case of June, July, and August 1877, and March, April, and May 1879, in the North-Western Provinces; and many others may be noticed, in glancing through the tables of temperature anomalies in the annual meteorological reports. On the other hand, to the same modifying influence, may probably be traced in a large measure, the fact that homonymous months may be very similarly characterised by unusual dryness or dampness in two different years, and yet there may be a considerable difference in the temperature anomaly, if the period of a month or two immediately preceding has been of a different character in the two years compared. An instance of the kind has occurred during the present year (1880), which will be duly noticed in the annual report for that year.

To sum up the principal conclusions arrived at in the foregoing discussion. At all times of the year, the air temperature is dependent, 1st, on the quantity and intensity of the sunshine; 2nd, on the terrestrial radiation, which is predominantly active as a cooling action only at night; and 3rd, on the evaporation of rain. The influence of cloud, which checks both solar and terrestrial radiation, is such as, in conjunction with the rainfall, (which varies more or less *pari passu* with it), to lower the temperature from February to October, to raise it in November and December. On the mean of the whole year, therefore, cloud and rain exercise a preponderating cooling influence. The immediate effect of these agencies is, however, much modified by the condition of the ground, which acts as a reservoir of heat, and thus renders the temperature of any moderate period, to a certain extent, dependent on the condition of the period preceding it.

In general, and with but few and temporary exceptions, the pressure of the whole of India, was, throughout the year 1879, as persistently below the average, as it had been above it during the two years ending with August 1878; the depression, which set in in September 1878, having been almost continuous up to, at least, the end of 1879. As in the case of the preceding and opposite anomaly, this condition was evidently not due to the reduced density of the lower atmosphere, except partially in the months of April and May. For, the density of the lowest stratum, and therefore its static pressure, was above the average in March, and, in most cases, from June to the end of the year; on the mean of the whole year, the pressure of this stratum was in excess; as might have been expected from the fact, that its mean temperature was below the average; but this excess was more than neutralised by the deficiency of pressure of the higher strata, and the total pressure was in defect in all months, excepting July and partially in March, June, September, and November. Thus, then, we have, in 1879, conditions precisely the reverse of those obtaining in 1877 and the earlier part of 1878, when the temperature of the lower stratum being excessive, was accompanied by a density less than the average; but this anomaly was neutralised and outbalanced by the excessive pressure of the elevated strata.

Is this contrast of conditions in the lower and higher atmospheric strata, thus doubly illustrated in the barometric features of the last three or four years, a law of general incidence? and is it traceable to the play of physical processes which accompany these abnormal conditions? There are many circumstances which lead me to think this probable.

I must premise that the opposition of conditions, the coincidence of a decrease in the density of the higher with an increase in that of the lower strata of the atmosphere, and *vice versâ*, so far from being an extraordinary feature of our atmosphere, is one of regular annual occurrence in India. In Central India, May, in the North-Western Provinces either May or June, (according as the rains begin early or late), is the hottest month in the year. The first fall of rain brings about a rapid fall of temperature and with it a corresponding increase in the density of the lower air stratum; but notwithstanding this increase of density, there is no corresponding increase in the total pressure of the atmosphere. On the contrary, the minimum pressure does not occur until some weeks later; and, at the hill-stations, from 4,500 to 7,000 feet, above the plains, the pressure of the atmosphere continues falling till July. Hence, it must be concluded that the setting-in of the rains is accompanied by a decrease in the static pressure of the higher strata, which compensates, or more than compensates, the increased density of the lower. The following data serve to illustrate this:—

	Hoshangabad and Pachmarhi.			Roorkee and Chakrata.		
	May.	June.	July.	May.	June.	July.
Temperature of lower station,	92·7°	88·1°	79·5°	87·7°	90·2°	84·6°
Pressure of lower station, ...	28·675″	28·584″	28·592″	28·754″	28·615″	28·617″
Barometric weight of intervening air stratum, ...	2·340″	2·332″	2·367″	5·545″	5·462″	5·499″
Pressure of upper station, ...	26·335″	26·252″	26·225″	23·209″	23·153″	23·118″

On the other hand, the months in which the temperature is lowest on the plains, and the lowest stratum of air, on the average, most dense, are December and January; but at the level of the Himalayan hill-stations Murree, Chakrata, Darjeeling, &c., the pressure in December is lower than, in November, and in January still lower; and at that of Leh it falls from October to February, in which month, according to our present data, occurs the absolute minimum pressure of the year. These facts seem to point to the conclusion that, at some greater elevation, (perhaps at that of the Karakoram plateau), the annual oscillation of pressure is probably approximately the reverse of that which takes place on the plains of India, the maximum occurring when, in the lower atmosphere, the summer monsoon is at its height; and the minimum in January or February.

In seeking the physical explanation of these changes, it may be postulated at the outset, that the variations in the density of the atmosphere with which we have to deal, whether those of the higher or lower strata, are mainly due to variations of mean temperature; to which, indeed, the influence of variations in the quantity of vapour constituent, (regarded as replacing dry air of the same tension), is of quite subordinate importance. I have shown elsewhere, that the reduction of barometric weight, which a column of air, 7,000 feet high, undergoes from January to July, over the plains of Bengal, is due to the rise of temperature in the proportion of $\frac{11}{13}$, to only $\frac{2}{13}$, consequent on the replacement of dry air by vapour; and the relative importance of temperature may be shown more in detail and with more direct reference to the present discussion, by the following comparison of the temperature and barometric anomalies, extracted from Tables XI and VIII in the Report on the Meteorology of 1879.

	Chakrata and Roorkee.		Ranikhet and Bareilly.		Pachmarhi and Hoshangabad.	
	Barometric anomaly.	Mean temperature anomaly.	Barometric anomaly.	Mean temperature anomaly.	Barometric anomaly.	Mean temperature anomaly.
January	—·007	+2·0	—·010	+2·7	—·002	+0·3
February	—·019	+1·3	—·014	+1·5	+·041	+0·9
March	+·011	—0·4	+·007	—0·4	+·014	—1·7
April	—·035	+3·6	—·038	+3·5	—·021	+0·8
May	—·044	+4·3	—·048	+5·4	—·015	+0·7
June	+·055	—2·6	+·046	—1·6	+·014	—1·8
July	+·042	—1·5	+·044	—1·9	+·001	+0·4
August	+·031	—2·0	+·030	—1·6	+·014	—1·3
September	+·024	...	+·017	—0·1	+·021	—1·1
October	+·009	...	+·002	—0·4	+·009	—1·6
November	+·067	—2·5	+·037	—2·7	+·034	—4·9
December	+·028	—1·3	+·015	—2·4	+·024	—5·1

Considering the character of the data, that they can be regarded, at best, as affording rough approximations to the mean condition of the atmospheric stratum dealt with, as regards both density and temperature, and that variations of superincumbent pressure and humidity are entirely left out of account, the opposite march of temperature and density, exhibited by this table, is sufficiently striking, and affords a very satisfactory confirmation of the fundamental postulate. With respect to the higher atmospheric strata, direct evidence is of course wanting; but it may fairly be inferred that the variations of temperature therein, are at least as influential, relatively, on the density, as in the lower atmosphere here dealt with.

If these views be admitted, the frequent concurrence of a diminished density in the lower strata with an increased density of the higher, and *vice versâ*, resolves itself into this, that the temperature of the higher and lower strata tend to vary at opposite directions, the one being in excess when the other is in defect; and the discussion of the problem resolves itself into that of the processes by which the temperatures of the lower and higher strata are respectively influenced.

The conditions which principally affect variations of temperature on the land, (in India) have already been discussed. It has been shown that the most influential of these are the presence or absence of cloud and the evaporation of rainfall. That, excepting in one or two of the winter months, an increase of cloud is accompanied by a reduction of temperature, and, at all seasons, without exception, the evaporation of rain produces a similar effect. But the effect of cloud and the precipitation of rain, on the temperature of the higher atmospheric strata, must be of precisely the opposite character. In the first place, the very condensation of the vapour which forms them, sets free a quantity of latent heat, which retards the fall of temperature, that would otherwise take place in every ascending current; and such currents exist in the large majority of rain clouds, if not in all; and, secondly, the solar radiation, which the cloud stratum shuts off from the earth, must be partly absorbed in the evaporation of the cloud surface.

Hence, there seems to be much probability, that the temperature anomalies of the higher strata of the atmosphere, as a general rule, are of the opposite character to those shown by our land observatories at low levels; but if so, the elevation at which this law holds good, must be considerably greater than that at which the hill observatories of the Himalaya afford the means of verifying it.

VII.—*Description of a rain-gauge with evapometer, for remote and secluded stations.* By H. F. Blanford, F. R. S., *Meteorological Reporter to the Government of India.*

(With Plate XV.)

[Received 25th March 1881. Read 6th April 1881.]

In the autumn of 1879, I received, through the Government of India, a description and sketch of a rain-gauge proposed by Mr. Hutchins, Assistant Conservator of Forests in Mysore, for the purpose of collecting the rainfall at remote and rarely visited stations, such as in certain forest tracts, and other places, where there are no permanent residents, and which can be visited only at longer or shorter intervals. There are, it is true, several forms of rain-gauge provided with mechanism for the purpose of registering the fall, but these are expensive at the outset, and if, as frequently happens, the mechanism becomes deranged, the gauge must as a rule be sent to a Presidency town or some large Government workshop for repair; involving further expense and an interruption of the record, at a time, perhaps, when it is most inconvenient.

Mr. Hutchins' idea was to provide a gauge of sufficient capacity to hold the rainfall of a month or even longer period, which might be measured on periodical visits to the station; and since, under such circumstances, there must always (except in prolonged wet weather) be an appreciable loss by evaporation, he proposed to use an evapometer with the gauge, which should show the evaporation in the intervals of the measurement; which quantity, being added to the rainfall collected and measured, would give the total fall in the interval.